Advancing Operational HWRF Model for Improved Tropical Cyclone Forecasts

Transition of HFIP Supported Research to Operations

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NOAA/NCEP/EMC

HFIP AO Round 2 Year 1 Review Meeting, June 11-12, 2015

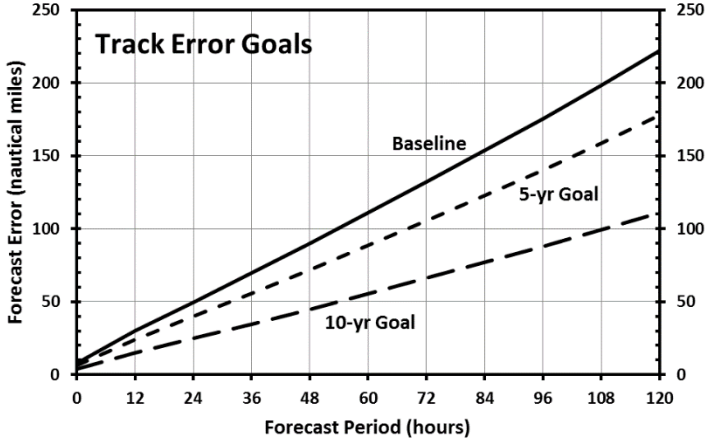
Aggressive Performance Goals

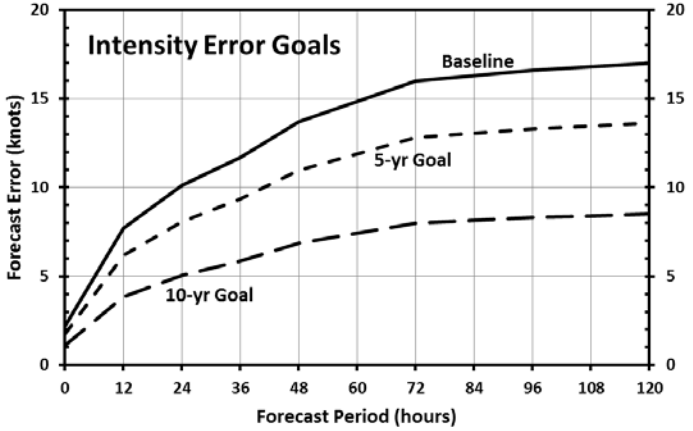
Vision

Organize the hurricane community to dramatically improve numerical forecast guidance to NHC in 5-10 years

Goals

- Reduce numerical forecast errors in track and intensity day 1 to day 5
  - 20% in 5 years,
  - 50% in 10 years
- Extend forecast guidance to 7 days with skill comparable to 5 days at project inception
- Increase probability of detection (POD) for rapid intensity change to 90% at day 1 decreasing linearly to 60% at day 5
- Decrease the false alarm ratio (FAR) for rapid intensity change to 10% for Day 1 increasing linearly to 30% at Day 5
- Improve storm surge prediction

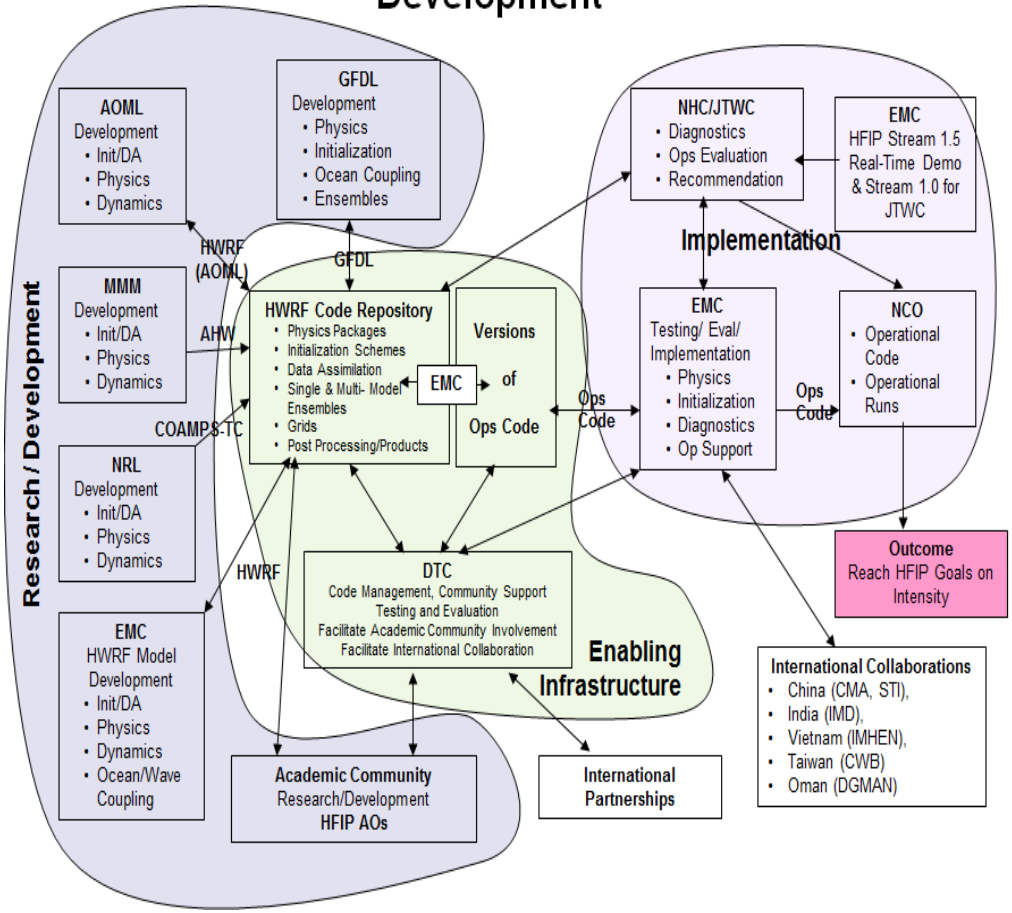


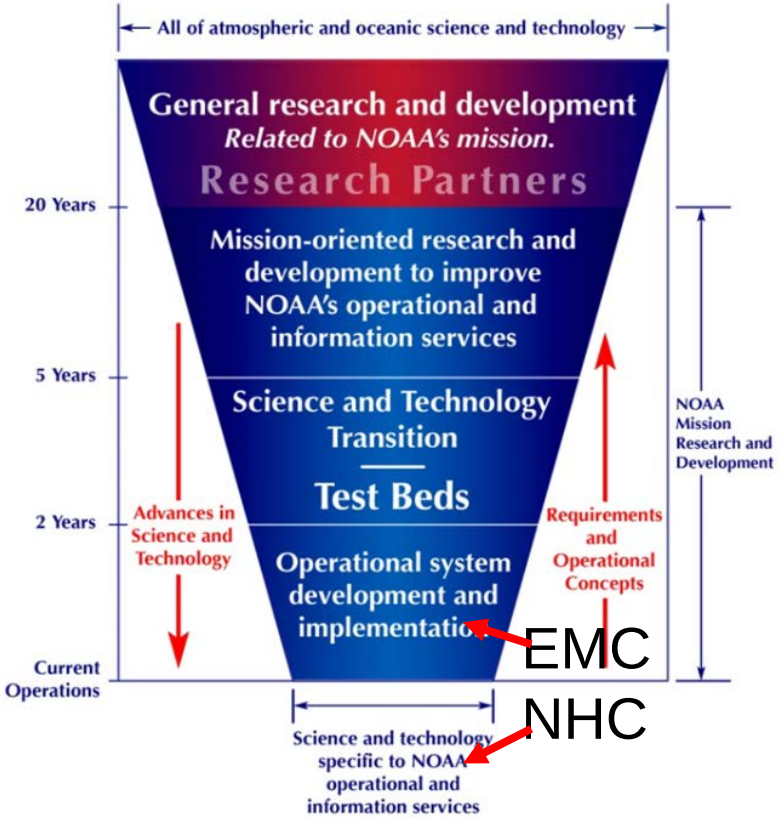


Key to Success: Community Engagement with Accelerated Research to Operations

HFIP Enabled R2O Infrastructure for HWRF Development Process

Operational Hurricane Modeling System Development



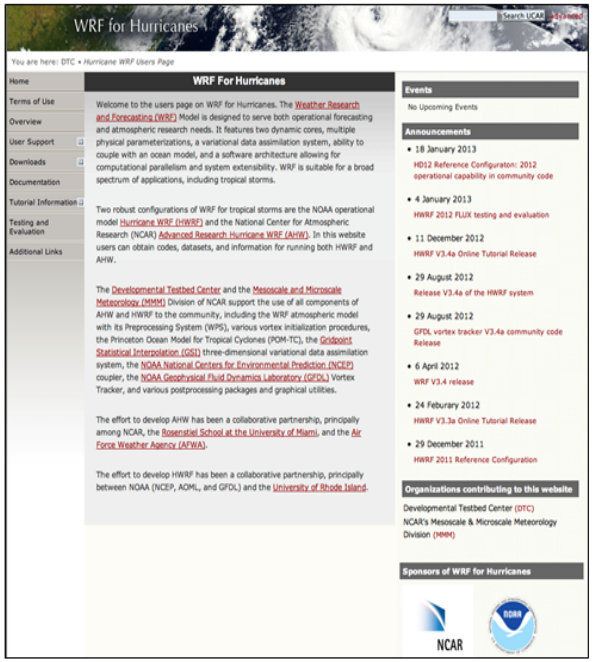


HFIP Enabled R2O Infrastructure for HWRF Development Process

www.dtcenter.org/HurrWRF/users

www.dtcenter.org/HurrWRF/developers

Support to users and developers



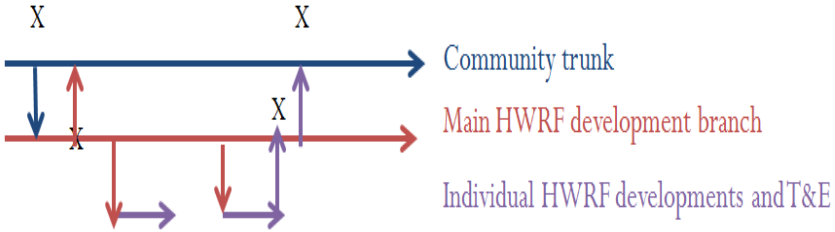
800 registered users

Stable well-tested code downloads, documentation, helpdesk

Yearly releases: current HWRF v3.6a (2014 operational)

Tutorials in 2014
- College Park, MD
- Taiwan

HWRF Code Management: HWRF code repository (housed at DTC) is a single code base for all developers – allows NOAA to benefit from external collaborators



HWRF IT infrastructure to support development

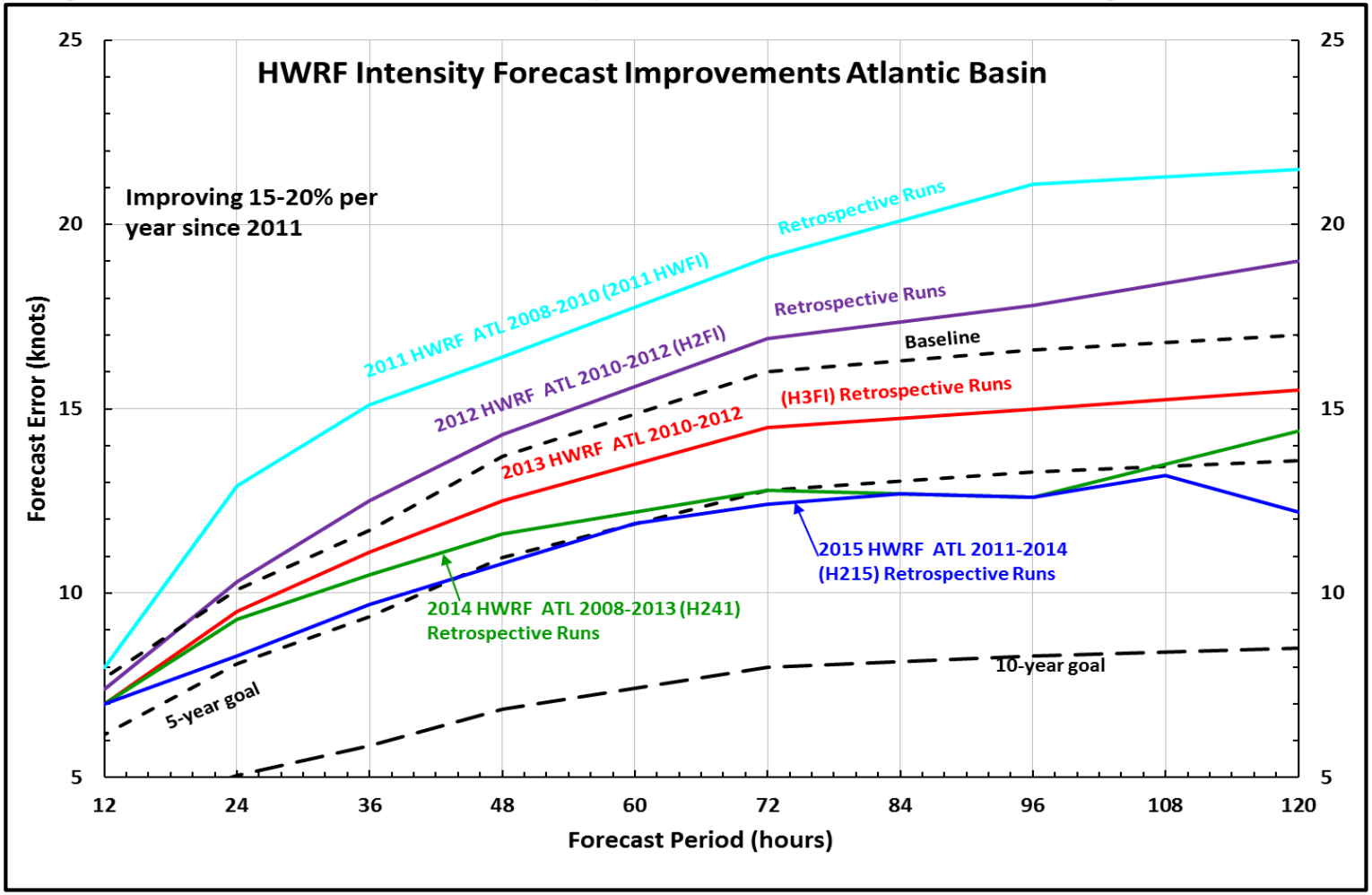
Support to developers
- Direct access to code repository
- Use of experimental configurations
- Code integration to avoid divergence
- Collaboration among developers

Highlights of FY15 HWRF Upgrades

- **System & Resolution Enhancements**
  - GFS data Upgrades
  - *Increase the horizontal resolution of atmospheric model for all domains from 27/9/3 to 18/6/2 km.*
- **Initialization/Data Assimilation Improvements**
  - Upgrade and improve HWRF vortex initialization and data assimilation system
- **Physics Advancements**
  - Upgrade Micro-physics (Ferrier-Aligo), surface physics and PBL
  - Implement RRTMG radiation scheme with partial cloudiness
  - Implement NOAH land surface model.
- **First time in 2015….**
  - *Self cycled HWRF ensembles based warm start for TDR DA*
  - *Expand HWRF capabilities to all global (including WP/SH/IO) basins through 7-storm capability in operations to run year long*

HWRF Intensity Error Improvements Atlantic Basin (2011-2015)

4 years of continuous improvements in intensity forecasts



HFIP Strategy and Tiger Teams to accelerate model development, testing and evaluation

HFIP Teams	Contributions for Research Transitioned to Operations
Model and Physics Strategy Team	Strategic design of annual upgrade implementation plans Establish infrastructure and support for community model development Engage research community in advancing research and development for hurricane modeling techniques and physics
Data Assimilation Strategy Team	Develop advanced vortex scale data assimilation techniques: Ensemble based hybrid EnKF-3DVAR DA Self-cycled high-resolution EnKF based ensembles for DA Cloudy radiance assimilation using innovative micrphysics independent techniques Impact assessment of aircraft data, GOES AMVs, microwave derived temperature anomalies and other cloud impacted satellite radiance data
Post-Processing and Verification	Advanced synthetic satellite imagery; high-frequency model output for track, intensity and structure; hurricane related tornado genesis products, ensemble based probabilistic products for genesis, wind and precipitation; statistical predictors for intensity using consensus of global and regional models (SPICE); advanced model diagnostics tools and verification techniques

HFIP Strategy and Tiger Teams to accelerate model development, testing and evaluation

HFIP Teams	Contributions for Research Transitioned to Operations
HRPTT *(components in bold transitioned to ops)*	Test most promising alternate physics packages ((2011-2012-2013) ***NOAH LSM, RRTMG Radiation; Observations based GFS PBL and GFDL Surface Physics; GFS Shallow Convection;*** MYJ PBL; Thompson MP, Meso-SAS convection etc.
RDITT	Test and evaluate impact of Aircraft Reconnaissance Data assimilation. (2012-2013-2014): ***One-way hybrid DA for TDR and dropsonde data outside the inner core; 40-member warm start HWRF ensemble based DA with all inner core data including GH/UAV sondes.***
SDITT	Regional hybrid system for testing and assessing the impacts of satellite data assimilated in hurricane models (2013-2014-2015): AMSU temperature anomalies, high-res GOES AMVs, ***clear-sky radiance***
OMITT	Document the importance of ocean model impacts on hurricane intensity prediction: (2014-2015): Design and develop new and ***improved ocean initialization techniques*** and physics at air-sea interactions using observations
Stream 1.5 & HFIP Website	Test and evaluate most promising techniques evaluated by NHC and products displayed on HFIP website

HWRF Upgrade Plan for 2015 Implementation

Multi-season Pre-Implementation T&E

	GFS Upgrades	Model upgrades	Physics and DA upgrades				Combined
	Control (H15Z)	Baseline (H15B)	NOAH LSM (H15W)	Upgraded Ferrier (H15W)	RRTMG/ PBL/ Surface Physics (H15W)	DA* (H15T)	H215
Description	Create a new control configuration of 2014 Operational HWRF run with newly upgraded GFS T1534 IC/BC	1.Resolution increase: 18/6/2km w/ same domain size; 2. Python scripts 3. New GFS T1534 4. Init improvement, GFS vortex filter	NOAH LSM (w/ Ch cap over land)	Separate species, w/o advection	1.Radiation 2.Variable α 3.Scale-aware partial cloudiness scheme	Hybrid GSI/ HWRF-EPS based DA	Baseline + NOAH/LSM +newMP+RRTMG+ Surface Physics + PBL + DA changes
Cases	Four-season 2011-2014 simulations in ATL/EPAC, cases (~2300)	Four-season 2011-2014 simulations in ATL/EPAC, cases (~2300)	Priority cases	Priority cases	Priority cases	Only TDR cases for 2011-2014	Four-season 2011-2014 simulations in ATL/EPAC, cases (~2300) WP/SH/IO 2013-2014 (~1200 cases)
Platforms	Jet/WCOSS	Jet	WCOSS	Jet	Jet/Zeus	Jet	Jet/WCOSS/Zeus

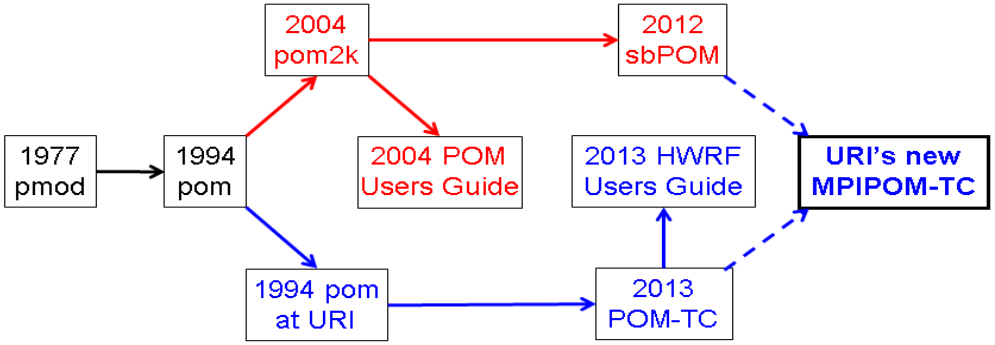
The plan is based on the assumption that 2015 operational HWRF system will have 3x computer resources within the HWRF operational time window. We will be using only 2.5X for each storm. DA experiment requires additional computer resources outside current operational time window.

HWRF Implementation Process at EMC for 2015 Upgrades

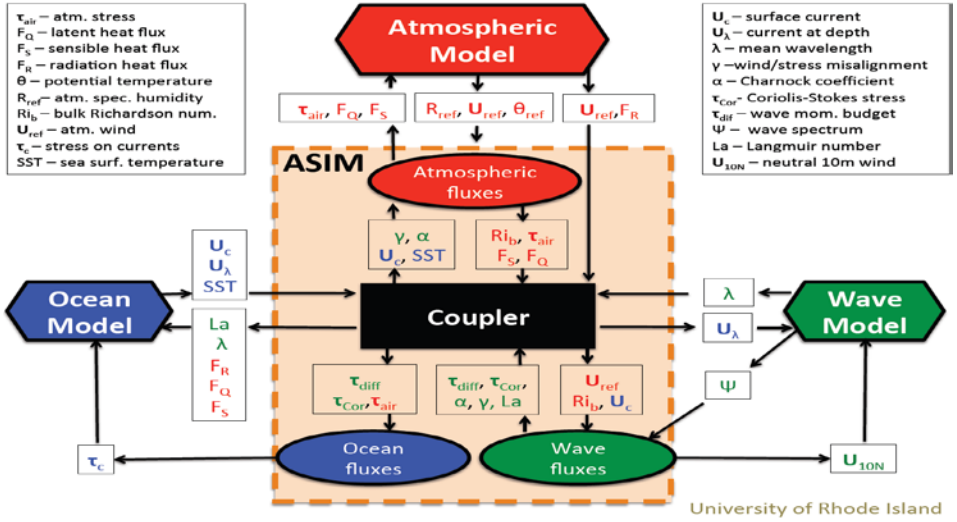
Strategy Teams	Tiger Teams	Academia (HFIP AOs)
HWRF Implementation: 1. HWRF Resolution upgrades 2. Vortex initialization improvements 3. Computational Efficiency 4. New products ***(U. Wisc.)*** and downstream applications 5. Expansion of HWRF to all global basins ***(JTWC/PR)*** 6. Unified Python based scripts and modern Rocoto based workflow ***(DTC/ESRL)*** 7. New setup procedures for HWRF/GFDL guidance	**HWRF Physics Improvements:** 1. RRTMG Radiation ***(EMC/DTC/NCAR)*** 2. NOAH LSM ***(EMC/NSF)*** 3. Ferrier-Aligo MP ***(EMC/ESRL)*** **HWRF DA upgrades** 1. 40-member HWRF ensembles for TDR DA 2. Assimilation of inner core dropsonde and tcvitals MSLP 3. New trigger mechanism for TDR DA ***(EMC/AOC/HRD)***	**HWRF Physics Improvements:** 1. Subgrid scale cloudiness parameterization for RRTMG radiation ***(NCAR/DTC)*** 2. Modified GFS PBL vertical mixing ***(UCLA)*** 3. Modified surface physics ***(GFDL/URI)*** **HWRF Diagnostics and Verification:** 1. Large-scale diagnostics and RI verification ***(DTC, SUNYA, CIRA)*** 2. Verification ***(EMC/NHC/DTC)***

R2O: Advancing Ocean/Wave Coupling for HWRF: URI (Planned for 2016)

POM community code development

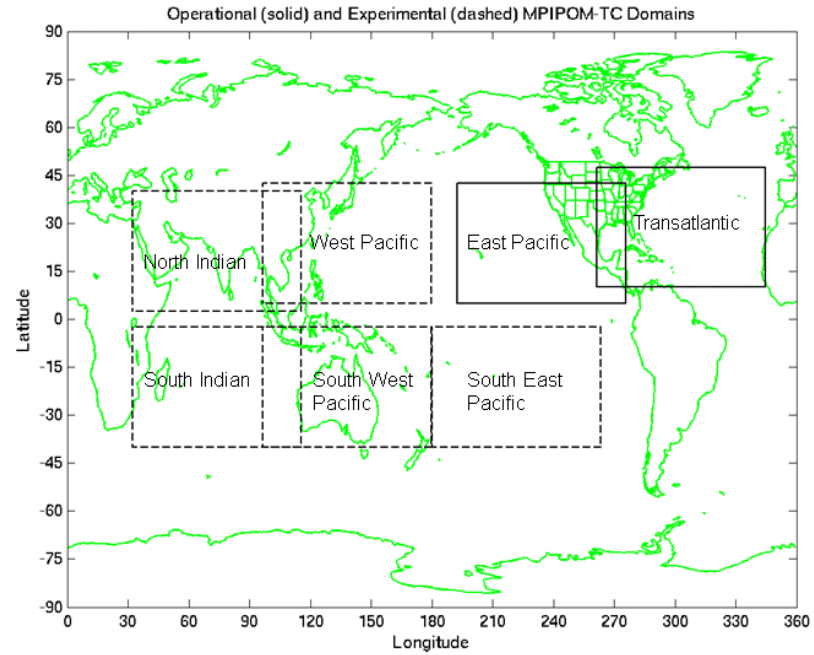


URI-based code development

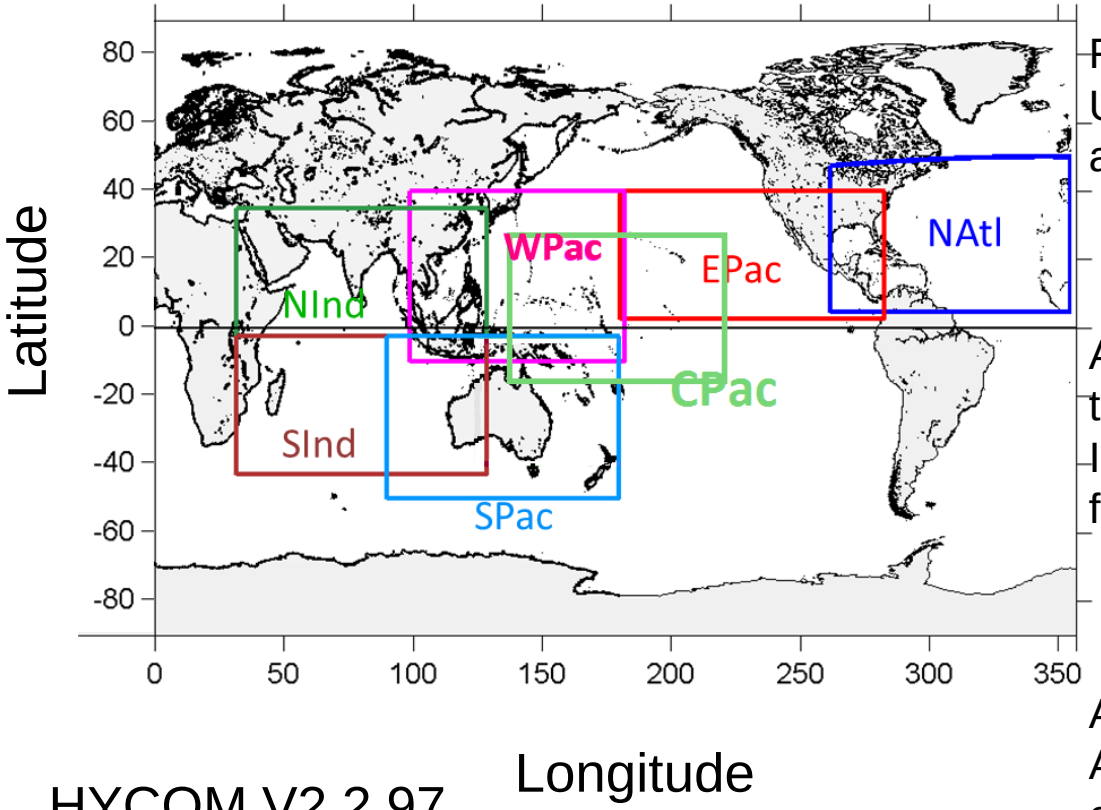


MPIPOM-TC for global basins is available through HWRF repository at DTC

Flexible initialization options:
NCODA, GDEMv3, HYCOM, or Feature-based (Atlantic only); with or without GFS SST assimilation
NetCDF I/O
Single prognostic code in all worldwide ocean basins



Experimental HWRF-HYCOM Coupled Model in 2015/2016



Finer resolutions in the upper layer,
Update physics and dynamics associated waves, Including
- Stokes drift
- Current-wave interactions
- Wave induced pressure changes

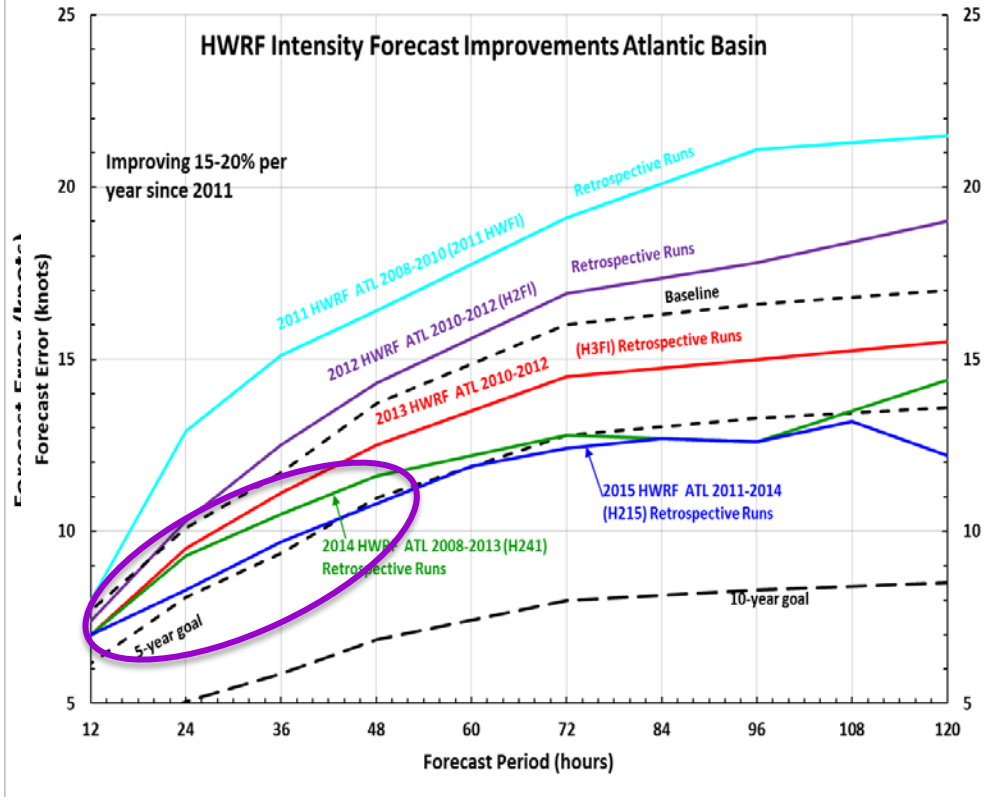
Advanced mixing, including Langmuir turbulence
Implementation of the pressure gradient forcing
- Better water level and currents simulations over the shallow waters

Ability to simulate precipitations
Ability to simulate river discharge via either as a source updates with USGS real-time water flow data or coupling a hydrology model
IC = Navy NCODA based nowcasts by global RTOFS
BC = 6 day RTOFS forecasts

<u>HYCOM V2.2.97</u>

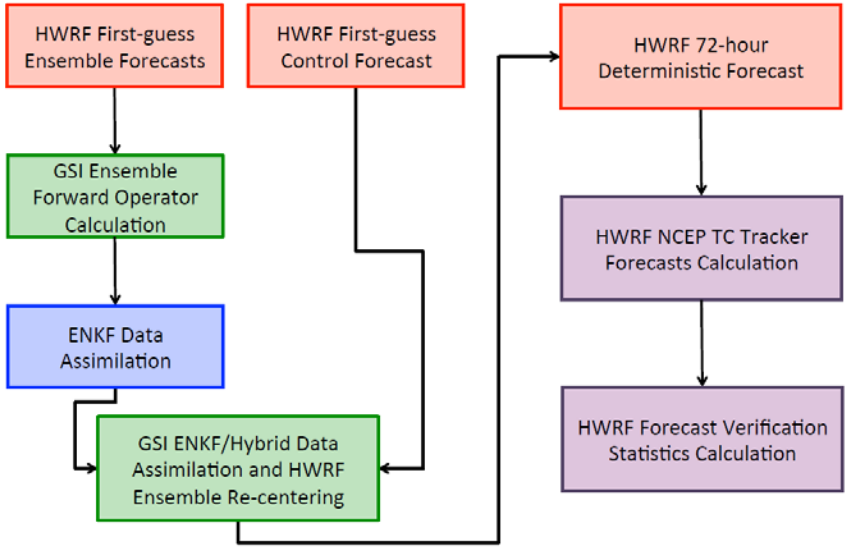
Each domain dimensions: ~9000km x ~5000km at 1/12-degree and ~25 vertical layers at dz ≥1m.

High Priority: Address Rapid Short-term Intensity Error Growth



Tropical Cyclone Initialization Strategy:

HWRF Forecast with TCs Initialized from GSI ENKF/Hybrid

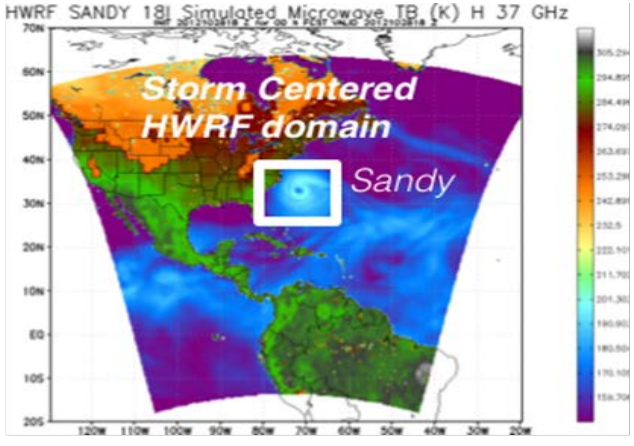


Development of Advanced Ensemble Based Hurricane Data Assimilation System: Another R2O effort in collaboration with ESRL, OU, Utah, PSU, U. Wisconsin, UMD & NESDIS

Next: Basin-Scale HWRF in NEMS

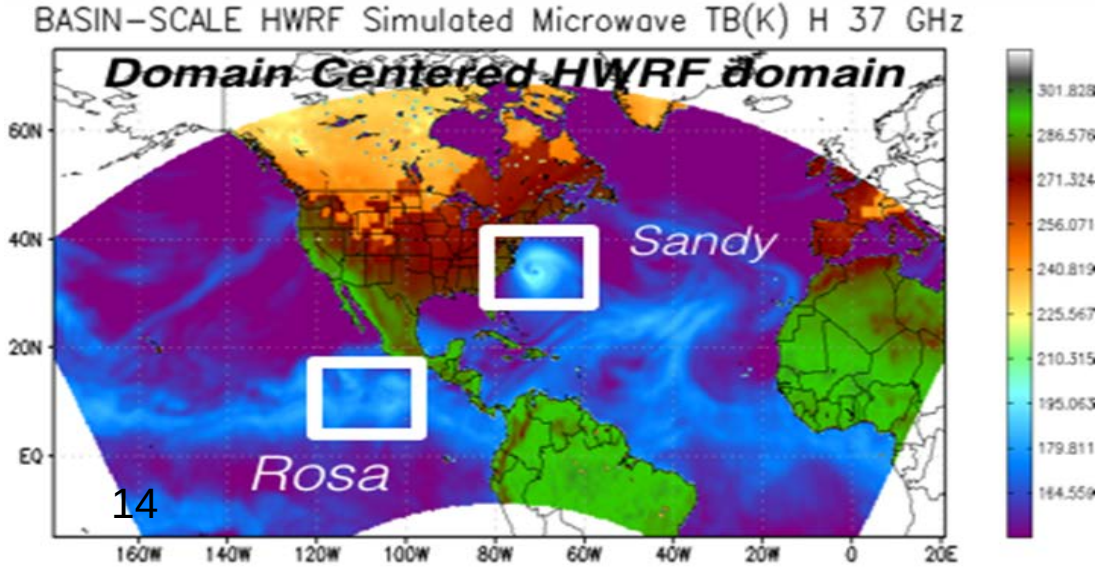
Storm Centric -VS- Domain Centric Forecasts

- Tropical Prediction System (Extended predictions)
- Improved storm-storm & multi-scale interactions
- Landfall and post landfall (storm surge & rainfall)
- Genesis; Regional ensembles; Data assimilation

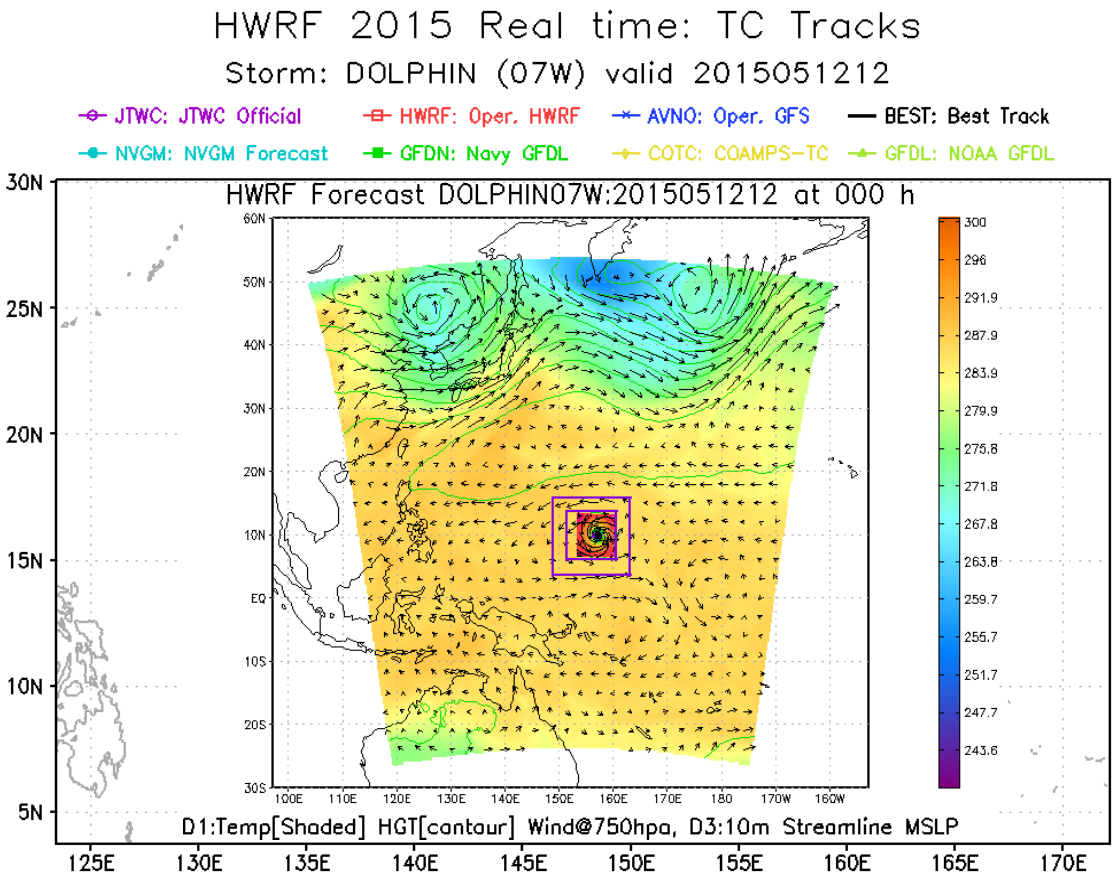


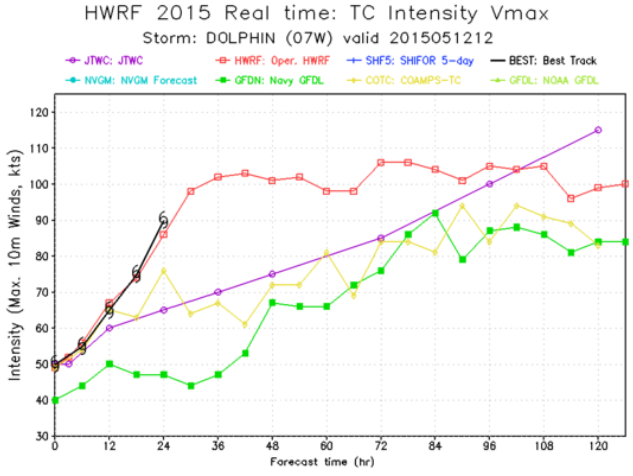
Transition HWRF into NMMB/ NEMS framework for Unified High-Resolution Mesoscale Modeling Suite at NCEP

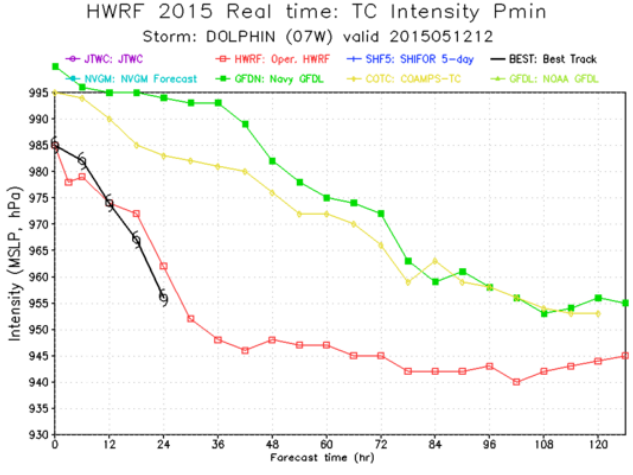
Future non-hydrostatic global models to include high-resolution moveable nests for more accurate predictions of significant weather events



Real-Time Example of Forecasts from 2km HWRF





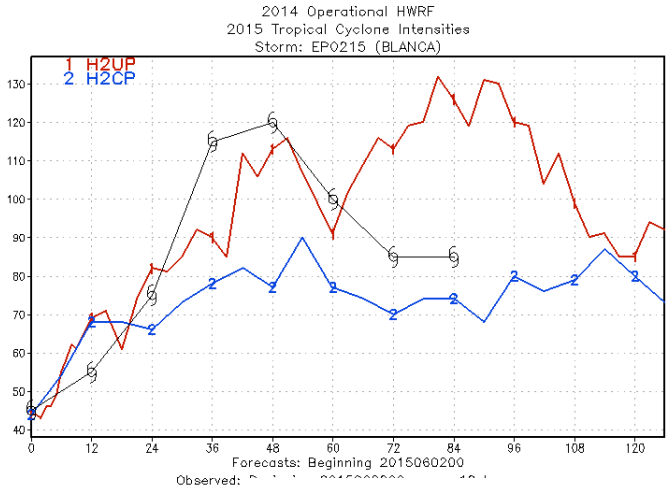


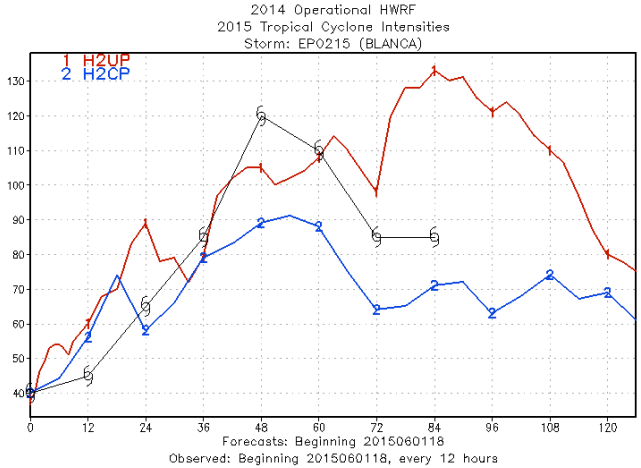
Telescopic storm-following high-resolution nests operating at 2km resolution near the storm center

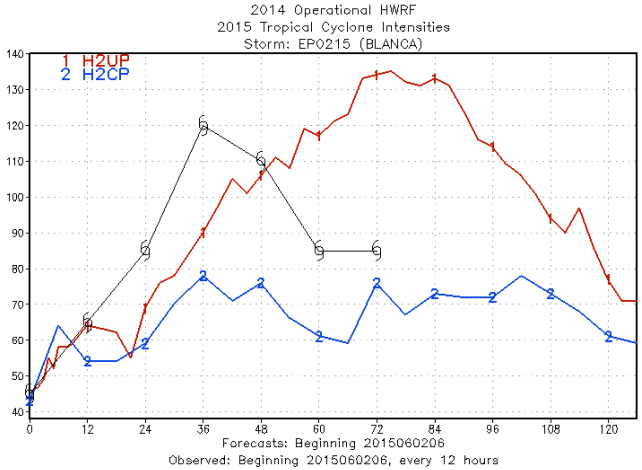
Ocean Coupling Impact: Blanca, 02E. FY 15 HWRF

FY15 HWRF: 18/6/2km

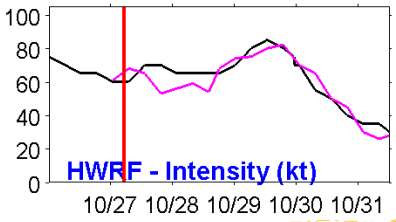
H2CP: Coupled
H2UP: Un-coupled

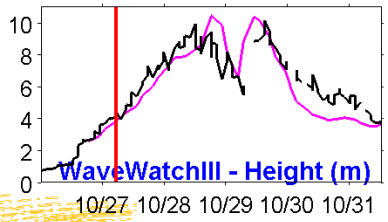






Advanced Storm Surge and Wave Products from Operational HWRF Coupled to ADCIRC and WaveWatch III





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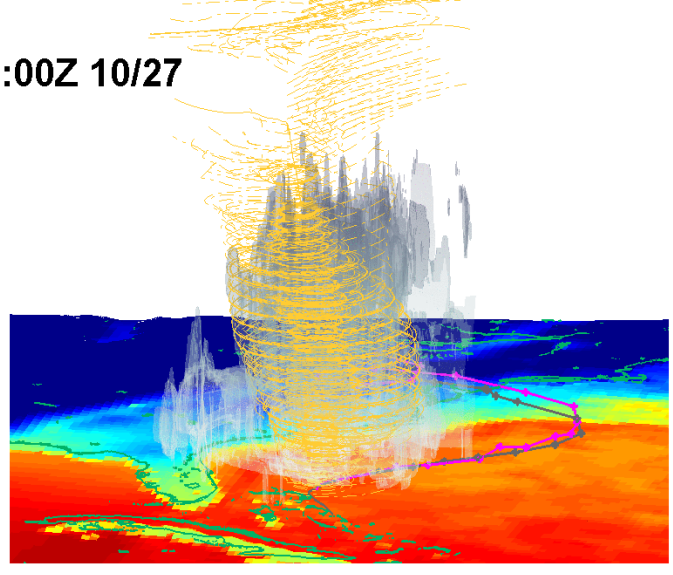
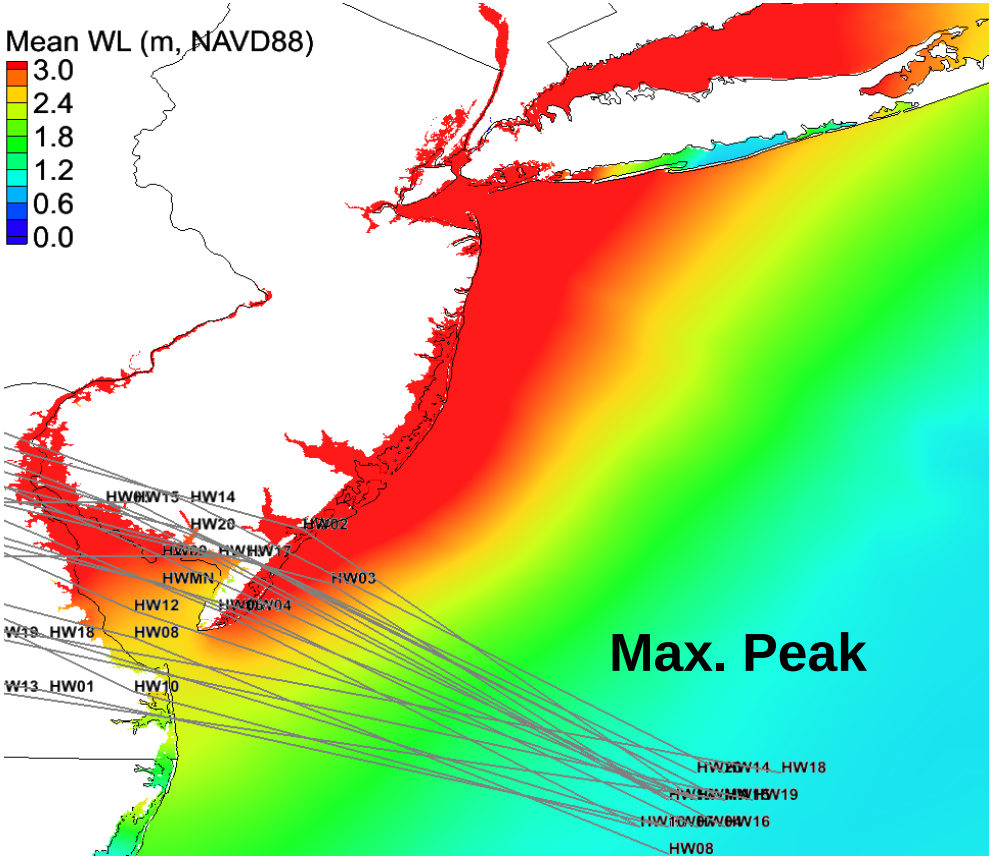
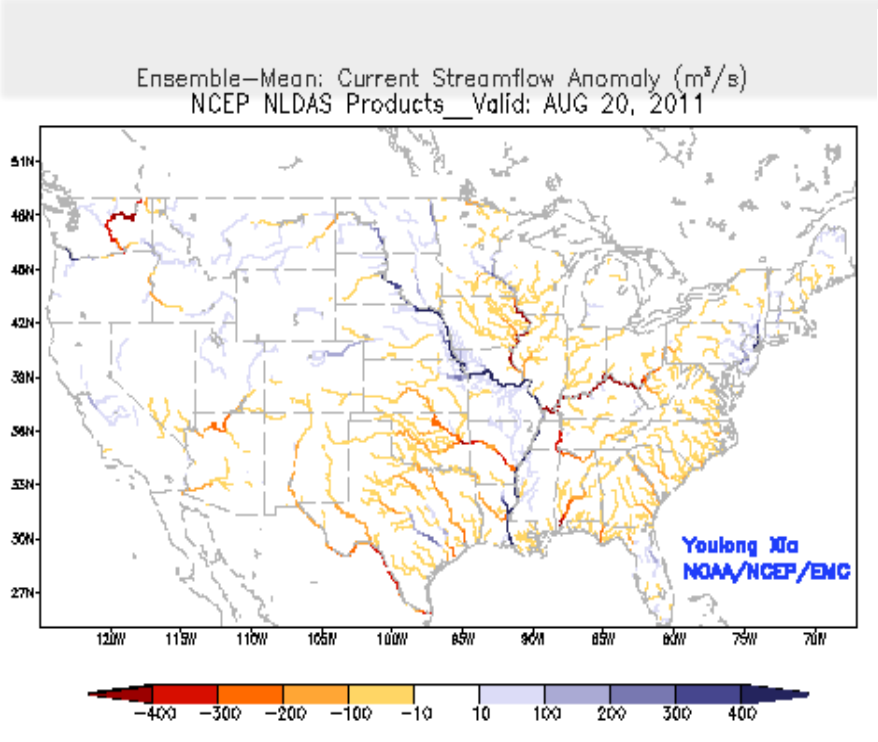
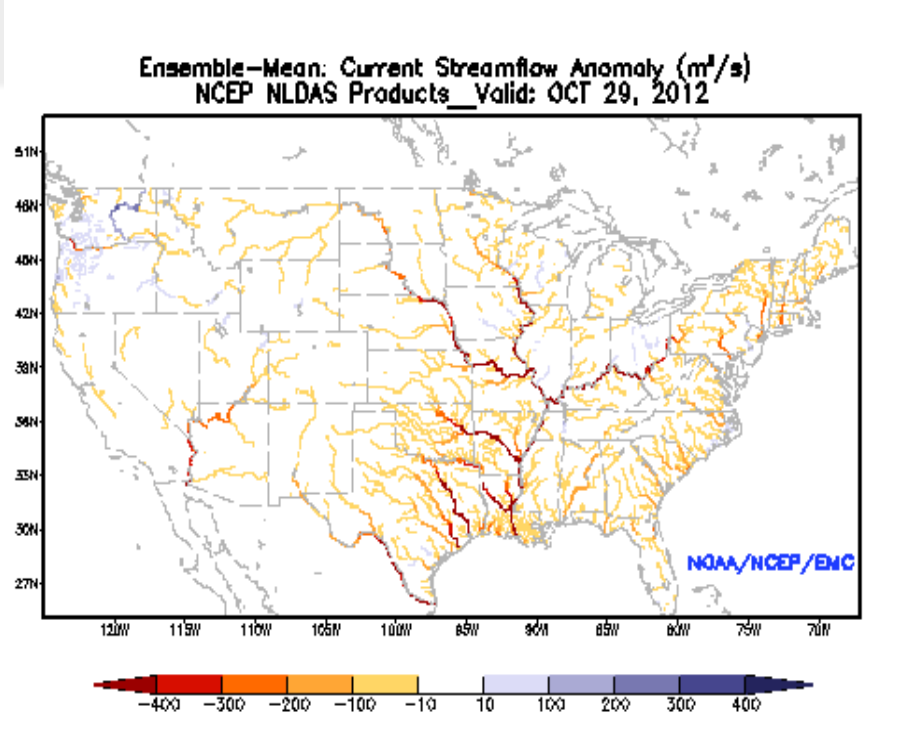




NLDAS Flood Monitoring

Ensemble mean daily streamflow anomaly (m^3/s)





Hurricane Irene and Tropical Storm Lee, 20 August – 17 September 2011;

Hurricane Sandy 29 October – 04 November 2012

Schedule of Operational Implementations

Activities	Approximate dates
Development of upgrades	Ongoing
Final development of proposed upgrades	September - December
Test of individual proposed upgrades	December - March
Final test of combined proposed upgrades	March
Pre-implementation test at NCO	April
HWRF operational implementation	**May**
HWRF public release	**August**

Available Resources

Resource	Comments
EMC	Code Development, support to developers, retrospective datasets, benchmarking operational system and advanced versions, Large-Scale testing and evaluation, pre-implementation tests, transition to operations, real-time demo
DTC	Code Management, support to users and developers, large-scale testing and evaluation, diagnostics, decision support
HRD/ESRL/ GFDL	Code development, diagnostics, observational datasets
Jet	Computational resources, real-time reservations
NHC	Product evaluation and guidance
HFIP PO	Monitor progress and provide support

Summary/Concluding Remarks

- **Focused research and development, planned testing and evaluation, sufficient computational resources and effective R2O strategies are the highlights of HFIP contributions towards hurricane forecast improvement (and set the pathway for reaching the goals set by NOAA HFIP)**
- **The Strategy Teams and Tiger Teams, closely coordinated development plans vetted through engaging the community from the beginning are fine examples and lessons learnt from HFIP.**
- **Success of HFIP supported Research transitionable to Operations requires close coordination with EMC, DTC and NHC**